WFIRST Science Definition Team and Project Final Report Presentation to HQ *

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James Green	SDT Co-Chair
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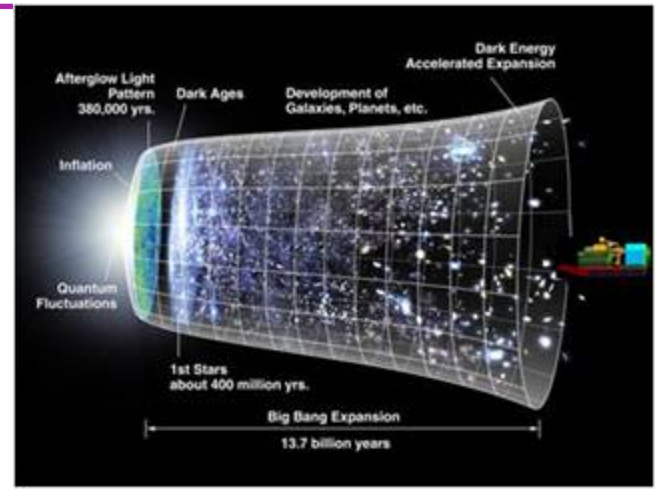
* These viewgraphs should not be read as a substitute for the full report.

July 12, 2012

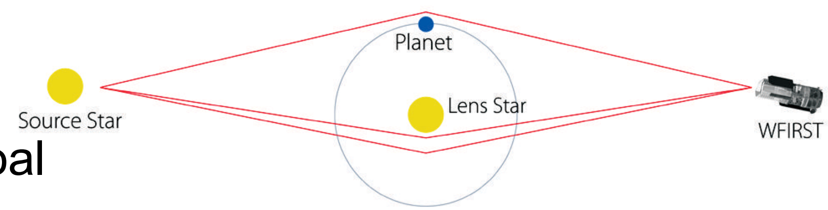
WFIRST Summary

❖ WFIRST is the highest ranked large space mission in NWNH, and plans to:

- complete the statistical census of Galactic planetary systems using microlensing
- determine the nature of the dark energy that is driving the current accelerating expansion of the universe
- survey the NIR sky for the community
- conduct a guest observer program



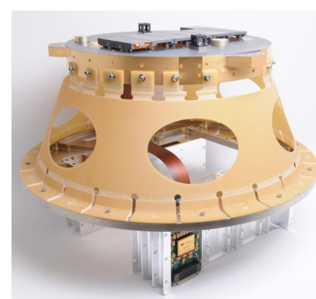
❖ Earth-Sun L2 orbit, 5 year lifetime, 10 year goal



❖ Measurements are

- NIR sky surveys for BAO and weak lensing and
- NIR monitoring for SNe and exoplanets

❖ Space-qualified large format HgCdTe detectors are US developed technology and flight ready



H2RG EDU FPA

H4RG Mosaic Plate

SDT original Charter

"The SDT is to provide science requirements, investigation approaches, key mission parameters, and any other scientific studies needed to support the definition of an optimized space mission concept satisfying the goals of the WFIRST mission as outlined by the Astro2010 Decadal Survey."

"In particular, the SDT report should present assessments about how best to proceed with the WFIRST mission, covering the cases that the Euclid mission, in its current or modified form, proceeds to flight development, or that ESA does not choose Euclid in the near future."

SDT Charter for Final Report

- December 7, 2011 Letter to SDT
  1. Finalize IDRM analysis started in 2011
     - ❑ Examine other options for reducing overall cost of mission
     - ❑ Launch capable by end of calendar year 2022
  2. Assess options to leverage off Euclid science
     - ❑ Develop a DRM that does not duplicate Euclid and LSST capabilities
     - ❑ Examine options for reducing overall cost of the mission
     - ❑ Launch capable by end of calendar year 2022
  3. SDT augmented with up to 6 new members
- March 1-2nd SDT Meeting
  1. Additional direction from HQ to develop a DRM that does not duplicate the capability of JWST along with Euclid and LSST.

WFIRST Science Definition Team

Paul Schechter, MIT Co-Chair
James Green, U. Colorado/CASA Co-Chair

Rachel Bean, Cornell University
Charles Baltay, Yale
David Bennett, Univ. of Notre Dame
Robert Brown, STScI
Christopher Conselice, Univ. of Nottingham
Megan Donahue, Michigan State Univ.
Scott Gaudi, Ohio State Univ.
Tod Lauer, NOAO
Bob Nichol, Univ. of Portsmouth

Saul Perlmutter, UC Berkeley / LBNL
Bernard Rauscher, GSFC
Jason Rhodes, JPL
Thomas Roellig, Ames
Daniel Stern, JPL
Takahashi Sumi, Nagoya Univ.
Angelle Tanner, Mississippi State Univ.
Yun Wang, Univ. of Oklahoma
Edward Wright, UCLA

Neil Gehrels, GSFC Ex-Officio
Wes Traub, JPL Ex-Officio
Rita Sambruna, NASA HQ Ex-Officio

New Members Jan. 2012

Xiaohui Fan, U. Arizona
Chris Hirata, Caltech
Jason Kalirai, STScI

Nikhil Padmanabhan, Yale
David Weinberg, Ohio State U.

H4RG-10 Mosaic Plate with WFIRST Science Definition Team, NASA HQ, and Project Office Team February 3, 2012

WFIRST – Science Objectives

1) Complete a statistical census of planetary systems in the Galaxy, from the outer habitable zone to free floating planets, including analogs to all of the planets in our Solar System with the mass of Mars or greater.

2) Determine the expansion history of the Universe and its growth of structure in order to test explanations of its apparent accelerating expansion including Dark Energy and possible modifications to Einstein's gravity.

3) Produce a deep map of the sky at NIR wavelengths, enabling new and fundamental discoveries ranging from mapping the Galactic plane to probing the reionization epoch by finding bright quasars at $z>10$.

4) Provide a general observer program utilizing $\geq$10% of the mission minimum lifetime.

Euclid Context

The SDT was asked to consider the potential duplications of science capability between Euclid and WFIRST, (and LSST and JWST) and whether any cost savings could be realized by eliminating those duplications.

Euclid Context

The NRC Euclid report directly addressed this issue, independently of the SDT’s efforts. It concluded:

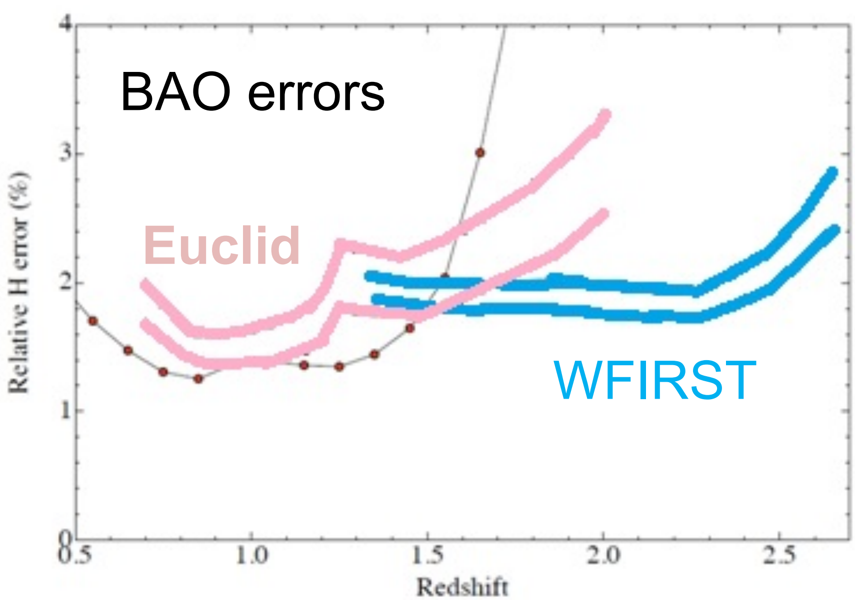
“Euclid's and WFIRST's measurements are *not duplicative* (emphasis added) and the combinations will be more powerful than any single measurement. Combining WFIRST with Euclid and ground based data sets, such as that expected from LSST, should further enable astronomers to address the systematic challenges that previous ground-based weak lensing measurements have experienced. These combined data sets will likely overcome systematic limitations and realize the full potential of this powerful technique.”

Euclid Context

The SDT agrees with the assessment of the NRC report, but notes in addition that a flexible WFIRST that flies after Euclid should have the ability to optimize its science program in light of the results of Euclid and ground based efforts.

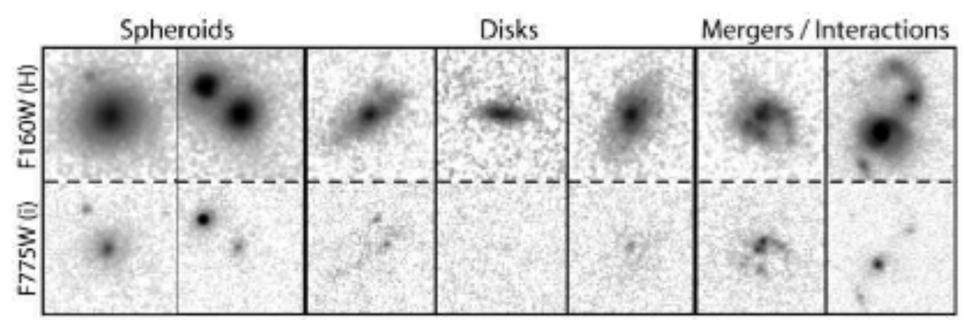
WFIRST – Euclid Comparison

Parameter	WFIRST	Euclid
Mirror diameter	1.5m (effective)	1.2m
Visible imager	none	36 CCD's
NIR imager spec	0.75x36 HgCdTe's	0.25x18 HgCdTe's
NIR pixel scale	0.18 " / pixel	0.30 " / pixel



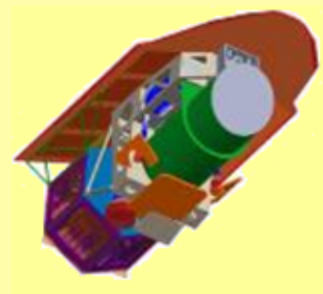
Wang & Bennett 2011

Kocevski et al. http://www.arxiv.org/pdf/1109.2588

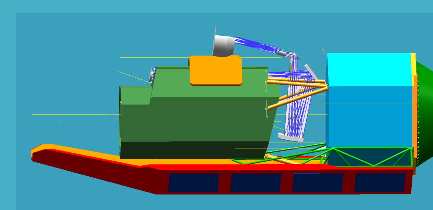


Design Reference Mission Options

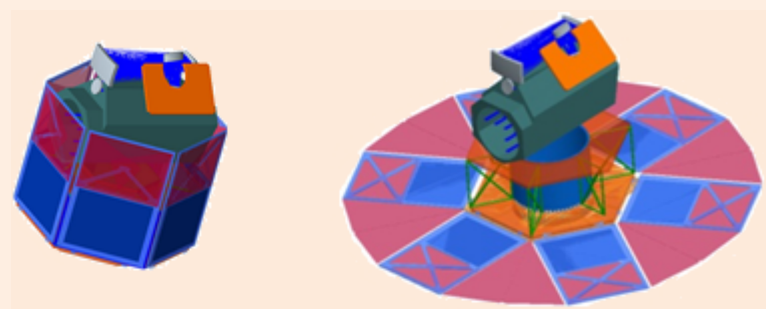
- **IDRM**
  - 1.3 meter off-axis telescope
  - 3-channel payload
  - 5 year mission
  - Atlas V Launch Vehicle



- **DRM1**
  - 1.3 meter off-axis telescope
  - Single channel payload
  - 5 year mission
  - Atlas V Launch Vehicle



- **DRM2**
  - 1.1 meter off-axis telescope
  - Single channel payload
  - 3 year mission
  - Falcon 9 Launch Vehicle



Key Hardware Changes

WFIRST DRM1, DRM2, vs. IDRM

- New for DRM1:
  - Single science channel, SpC SCA's moved to single larger focal plane array (FPA)
  - Prism wheel for spectroscopy (Galaxy redshift survey & SN prism assemblies) at same 0.18" pixel scale as imaging
  - Extension to 2.4um cutoff
  - Gold mirror coatings
- New for DRM2:
  - H4RG-10 focal plane array
  - Lightweight, compact design to fit on lower cost launch vehicle (Falcon 9)
- Unchanged:
  - Unobstructed three mirror telescope
  - Filter wheel after cold pupil
  - Auxiliary guider used during spectroscopy observations

	IDRM	DRM1	DRM2
Focal plane array type	H2RG	H2RG	H4RG
FPA layout	ImC 7x4, SpC 2(2x2)	9x4 H2RG	7x2 H4RG
Telescope aperture, m	1.3	1.3	1.1
Telescope temperature, K	220	205	205
Active field of view size, sq. deg.	ImC 0.291, SpC 2*0.26, total 0.81	0.375	0.585
GRS implementation	2 fixed opposed prism channels	prism wheel	prism wheel
GRS bandpass, um	1.3-2.0	1.5-2.4	1.7-2.4
Focal length scales with pixel size, m	20.63	20.63	11.46
Optical axis relative to fairing axis	parallel	parallel	perpendicular
Spacecraft redundancy	full	full	selected
Sunshield type	fixed	fixed	deployable
Launch Vehicle	AtlasV	AtlasV	Falcon9
Mirror coatings	protected silver	gold	gold

DRM1 Exoplanet Survey Capability

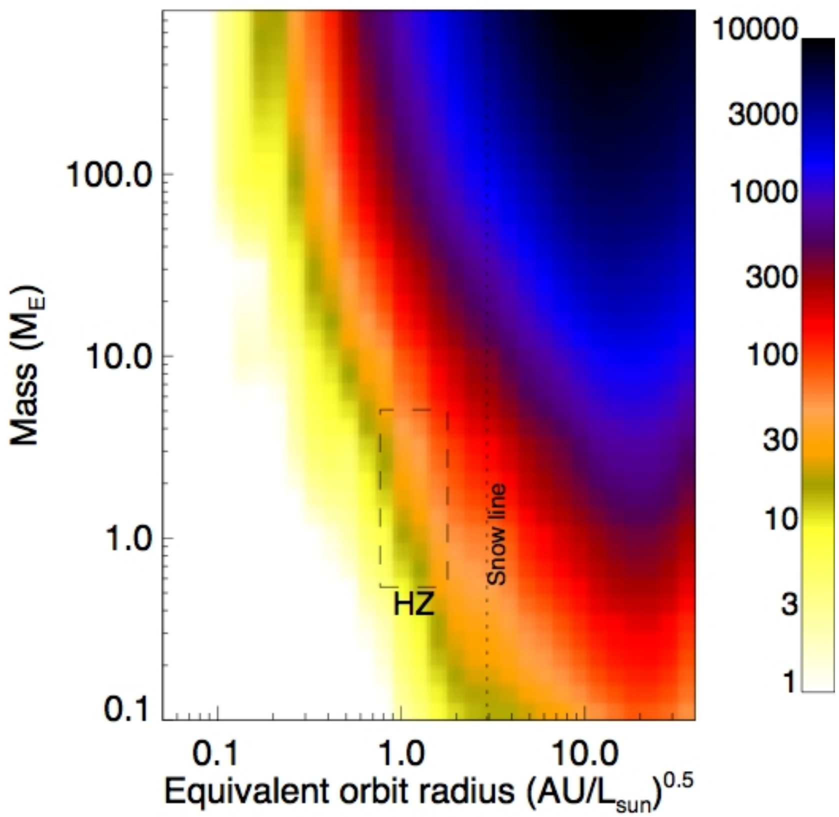
In 500 days of total exoplanet microlensing survey time, WFIRST.

- Demographics beyond the snow line, where the planets form
- Detects >2000 bound exoplanets in 0.1 – 20,000 Earth mass (M_{Earth}) and 0.3 – 30 AU
- Detects ≥ 100 free floating planets* of 1 M_{Earth}
- Detects ≥ 250 terrestrial planets* (0.3 – 3 M_{Earth})

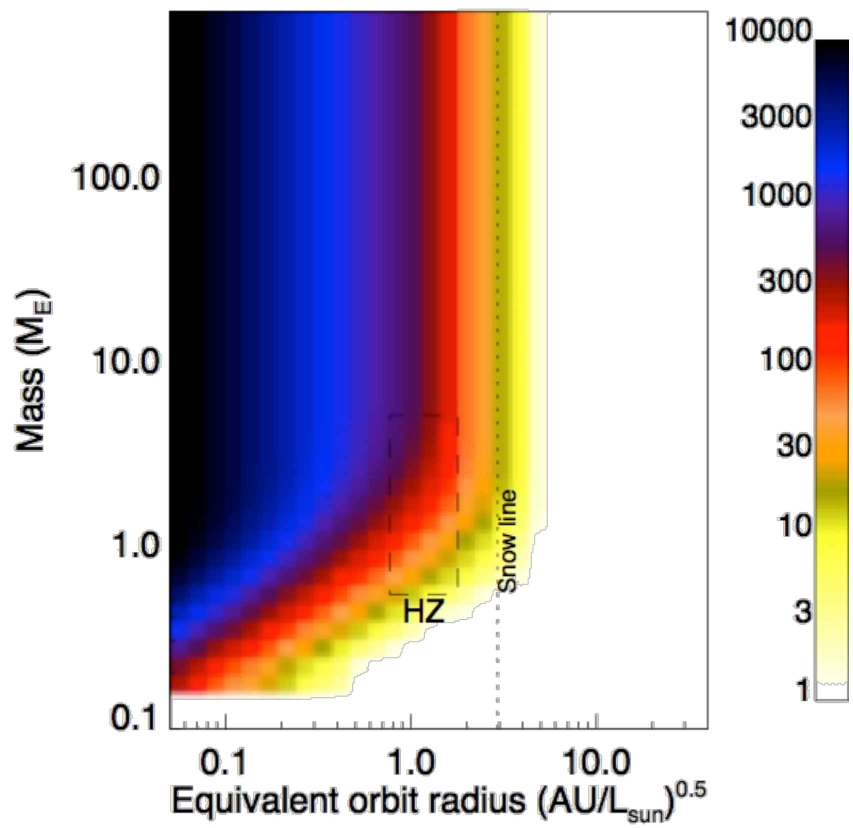
* Assuming one such planet per star; “500 day surveys” are concurrent

WFIRST Exoplanet Parameter Space

WFIRST



Kepler



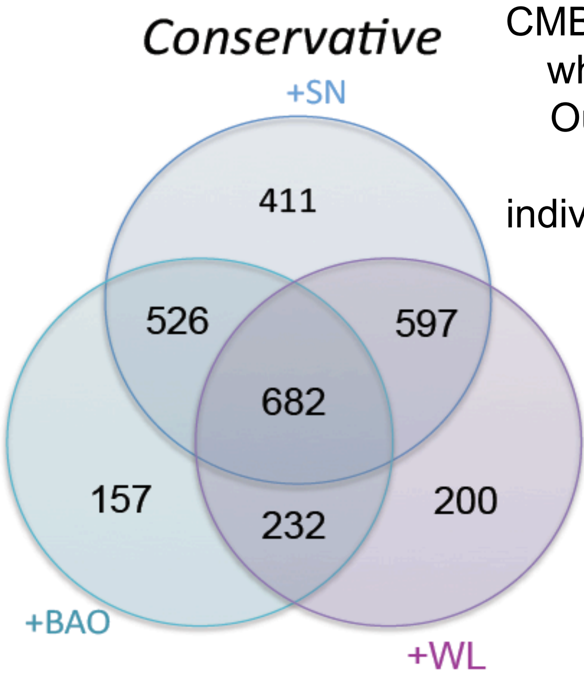
Figures from B. MacIntosh of the ExoPlanet Task Force

Cosmic Acceleration History DRM1 Capabilities

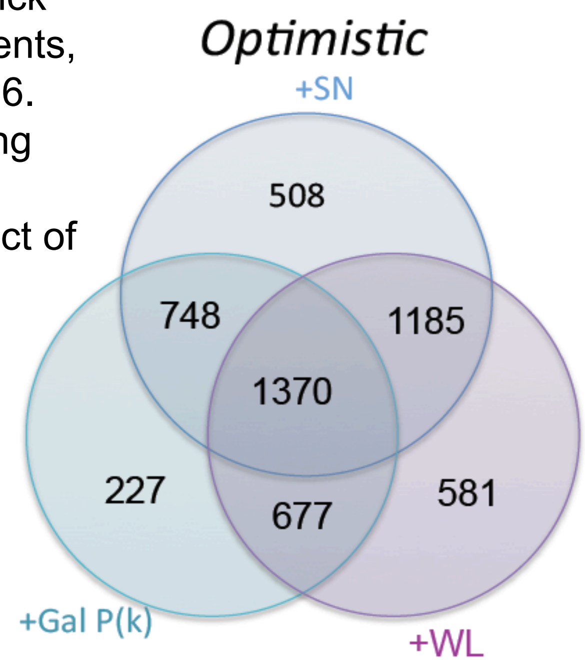
- BAO/RSD: covers 3400 deg^2 to a limiting Hα flux of 1×10^{-16} $ergs/cm^2/sec$ (7σ) at resolution R = 600 over the redshift range $1.3 < z < 2.7$.
- Weak Lensing: covers 3400 deg^2 to a limiting magnitude AB = 26 each in the Y, J, H and K filters yielding 30 $galaxies/arcmin^2$ in J, H and K.
- SNe-Ia: 2 tiered survey covering 6.5 deg^2 and 1.8 deg^2 with a five day cadence over 1.8 years yielding ~100 SNe per $\Delta z = 0.1$ bin for $0.4 < z < 1.7$.

DETF Figure of Merit

Forecasts of the DETF FoM for different combinations of the DRM1 WFIRST probes. All forecasts incorporate priors for Planck CMB and Stage III dark energy experiments, which on their own have an FoM of 116. Outer circles show the impact of adding WFIRST SN, WL, or BAO to these individually, and overlaps show the impact of adding combinations.



For this figure we adopt our conservative assumptions about SN and WL systematics, and we use only BAO information from the galaxy redshift survey. The FoM for all three probes combined is 682.



This figure is the corresponding diagram for the optimistic SN and WL systematics assumptions and the full P(k) analysis of the galaxy redshift survey. The FoM for each of the three methods improves, with a dramatic change in the case of WL, where the FoM nearly triples to 581. The combined FoM for the three methods is 1370, twice that of the conservative case.

DRM2 versus DRM1

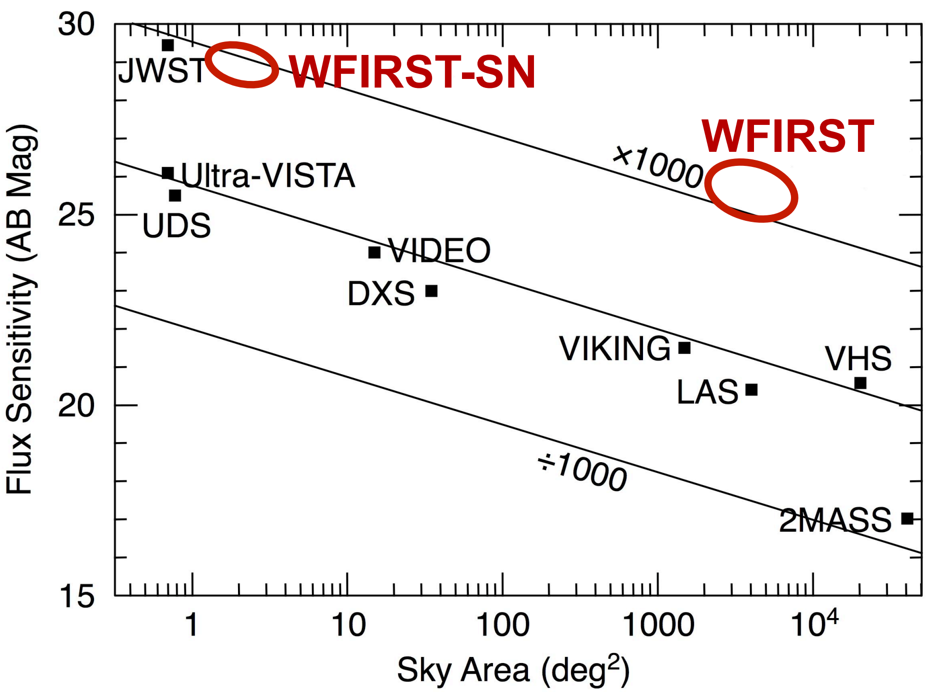
- DRM2 has only 60% of the observing time of DRM1. In the straw man allocations each program is reduced by this amount.
- extended sources: the figure of merit per unit time is the grasp – the field of view times collecting area. DRM2/DRM1 = 1.117.
- point sources: the figure of merit per unit time is the grasp divided by the diffraction limited solid angle. DRM2/DRM1 = 0.800
- BAO/RSD: The redshift survey is restricted to $1.6 < z < 2.7$ to compensate for the decreased observing time.
- Weak Lensing: DRM2 covers 2/3 the area of DRM1 with 25 resolved galaxies/deg^2 rather than 30.
- Exoplanet Microlensing: The shorter time baseline means that a smaller fraction of exoplanets will have measured masses rather than just mass ratios.

DRM 1 NIR Survey Capability

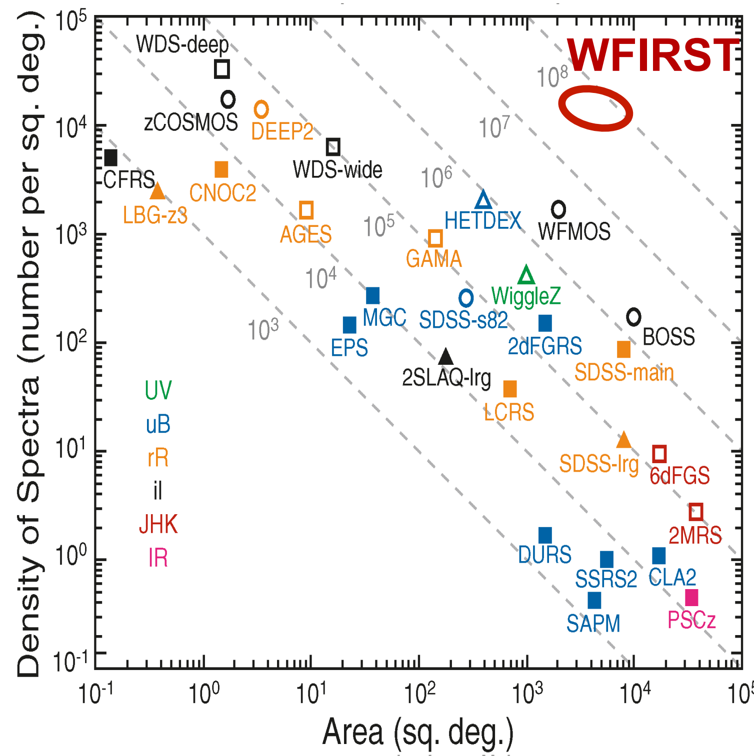
- Identify ≥ 2000 quasars at redshift $z > 7$ and ≥ 35 quasars at redshift > 10
- Obtain broad-band NIR spectral energy distributions of ≥ 3×10^9 galaxies at $z>1$ to extend studies of galaxy formation and evolution
- Map the structure of the Galaxy using red giant clump stars as tracers

WFIRST NIR Surveys

NIR Imaging Surveys



NIR Redshift Surveys

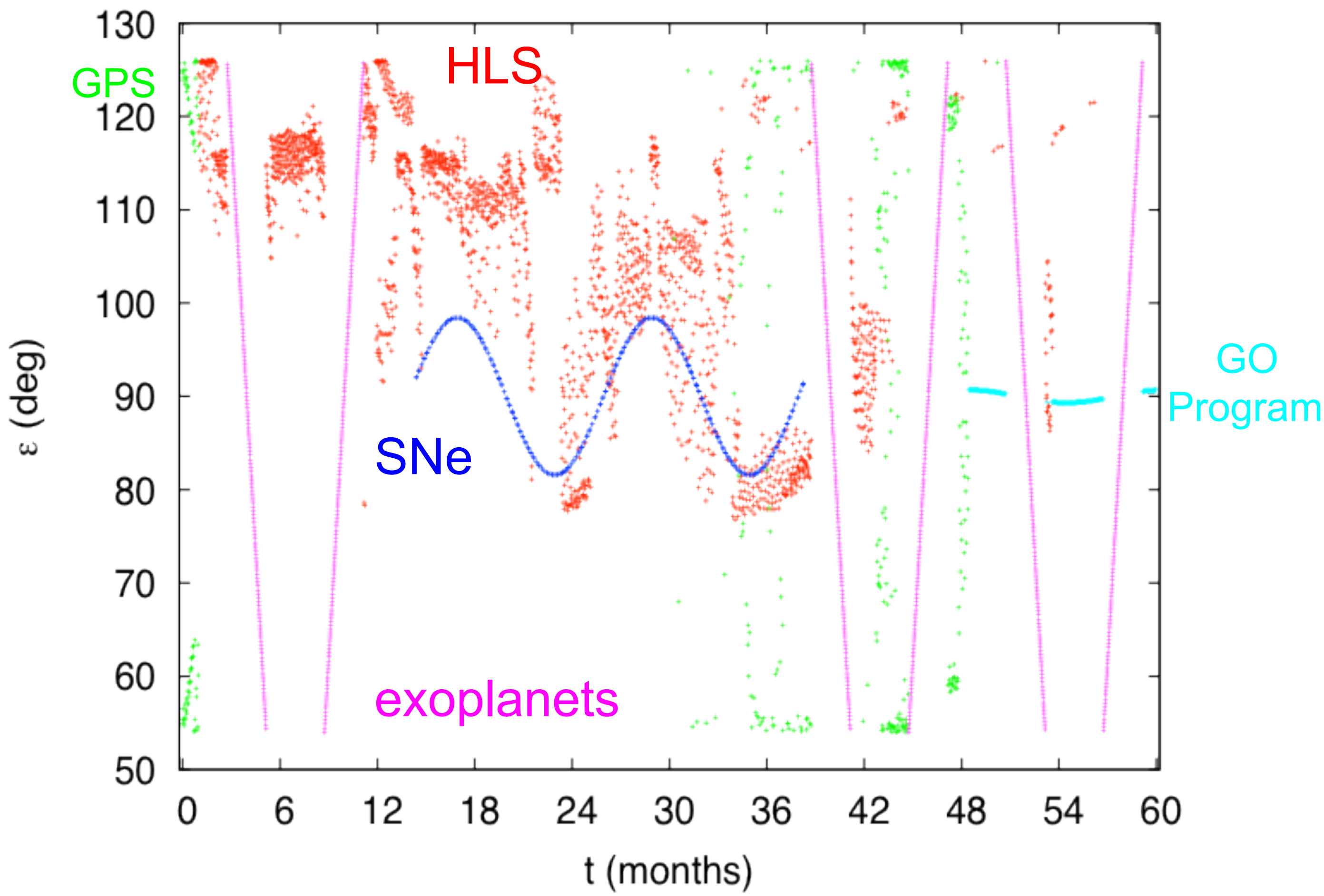


WFIRST provides a factor of 100 improvement in IR surveys

Survey Strategies

Example DRM1 Observing Plan

The horizontal axis shows time *t* from the start of observations, and the vertical axis shows the angle between the line of sight and the Sun (ε). The survey programs are color-coded: **red** for the HLS; **green** for the Galactic Plane survey; dark blue for the supernova survey; **magenta** for the microlensing survey; and **light blue** for the GO program



Straw Man Allocations

Program	DRM1	DRM2
exoplanet microlensing	14.4 months	8.9 months
general observer	6.1 months	3.6 months
supernovae	5.4 months	3.6 months
Galactic plane survey	5.3 months	3.4 months
high latitude imaging survey[a]	14.6 months	9.9 months
redshift survey[b]	14.2 months	6.5 months
Totals	5.0 years	3.0 years

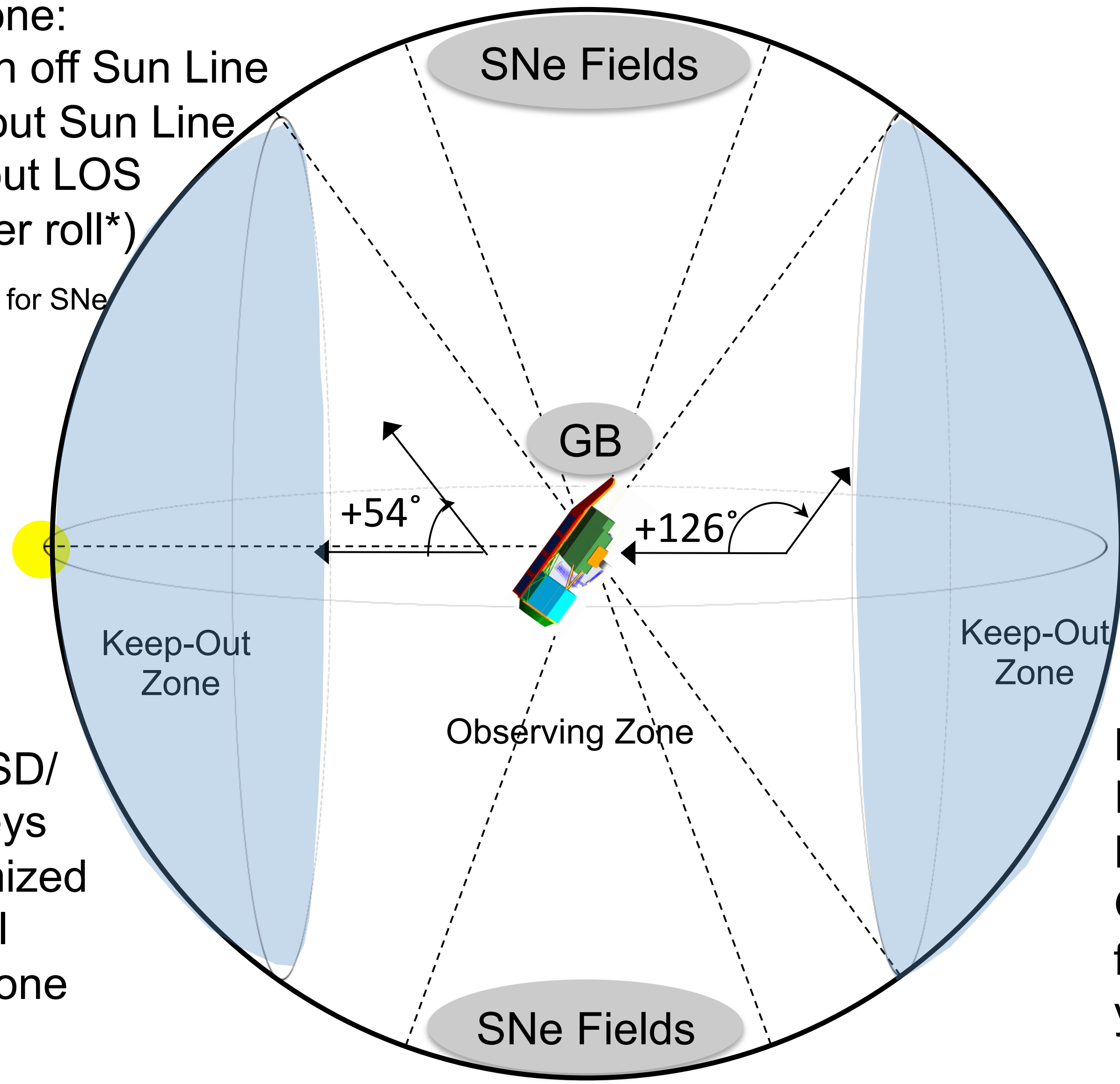
[a] includes weak lensing survey

[b] includes baryon acoustic oscillation survey

WFIRST's Central Line of Sight (LOS) Field of Regard (FOR)

Observing Zone:
54˚-126˚ Pitch off Sun Line
360˚ Yaw about Sun Line
±10˚ Roll about LOS
(off max power roll*)

* Larger roll allowed for SNe



SNe Inertially Fixed Fields must be within 20˚ of one of the Ecliptic Poles, and can be rotated every ~45 days

WL/ BAO-RSD/ GI/GP Surveys can be optimized within the full Observing Zone

ExP can observe Inertially Fixed Fields in the Galactic Bulge (GB) for 72 days twice a year

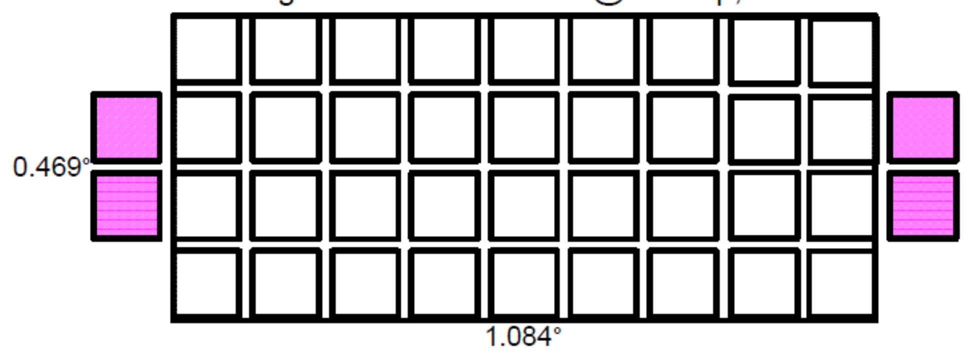
DRM1 Field of view & focal plane layout

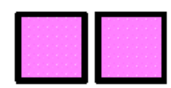
Channel field layout for WFIRST DRM1

1.3m uTMA, 9x4 single channel @0.18"/H2RG pixel

The Field of view of the single imaging & spectroscopy channel is shown to scale with the Moon, HST, and JWST. Each square is a 4Mpix vis-NIR sensor chip assembly (SCA)

Single channel FPA: 9x4 @ 0.18"/p;



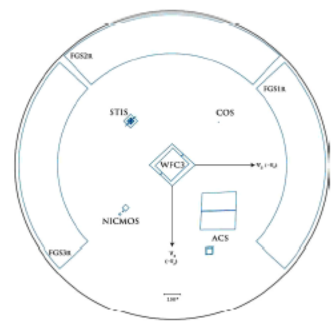


WFIRST-JWST Focal plane Comparison

- Area is 145x larger than NIRCAM (0.375 vs. 0.00259 sq degrees
- Focal plane has 5x more pixels than NIRCAM short wave cameras (150 vs 33 Mpix)

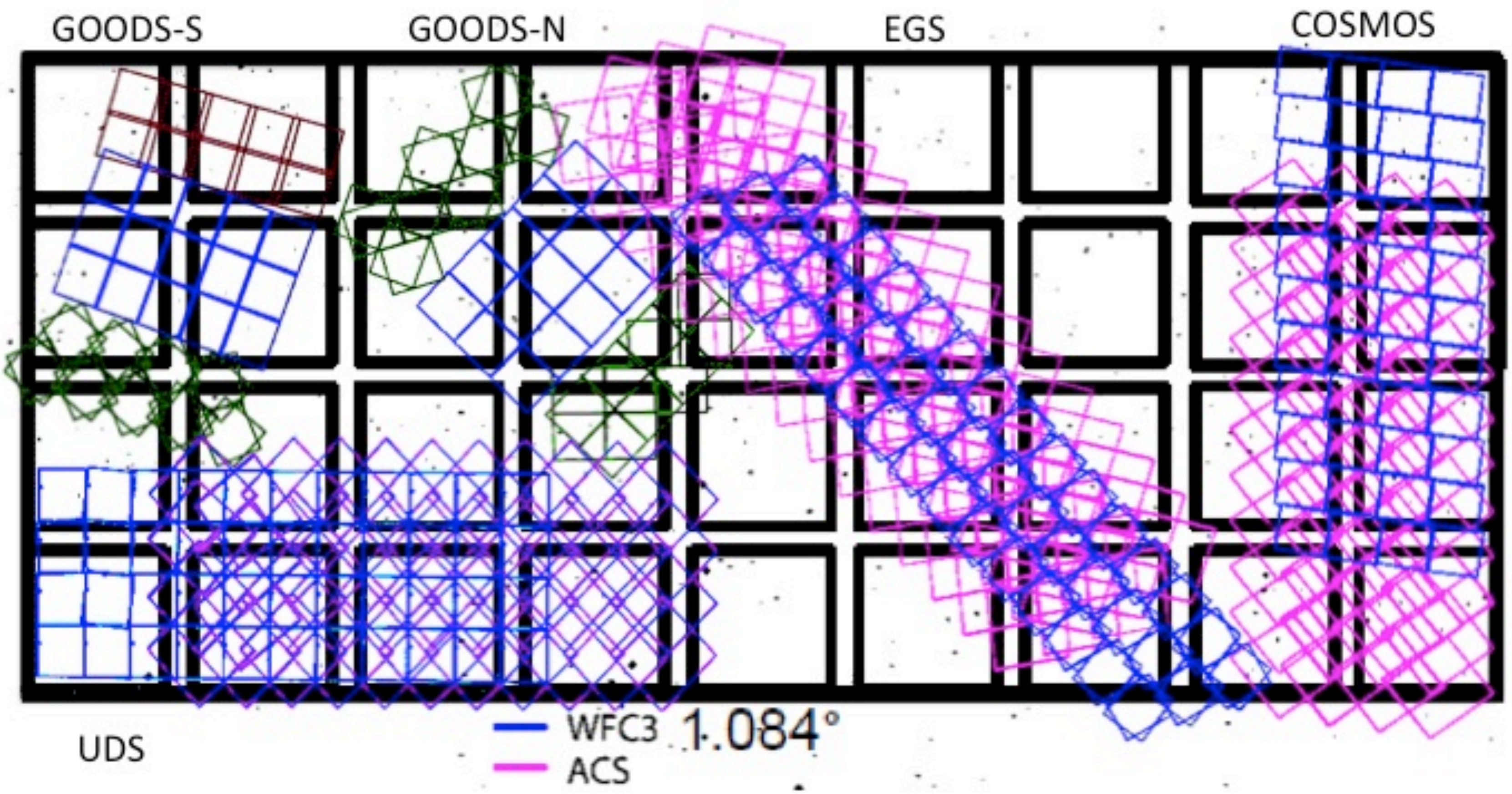
Moon (average size seen from Earth)

JWST [all instruments]



HST [all instruments]

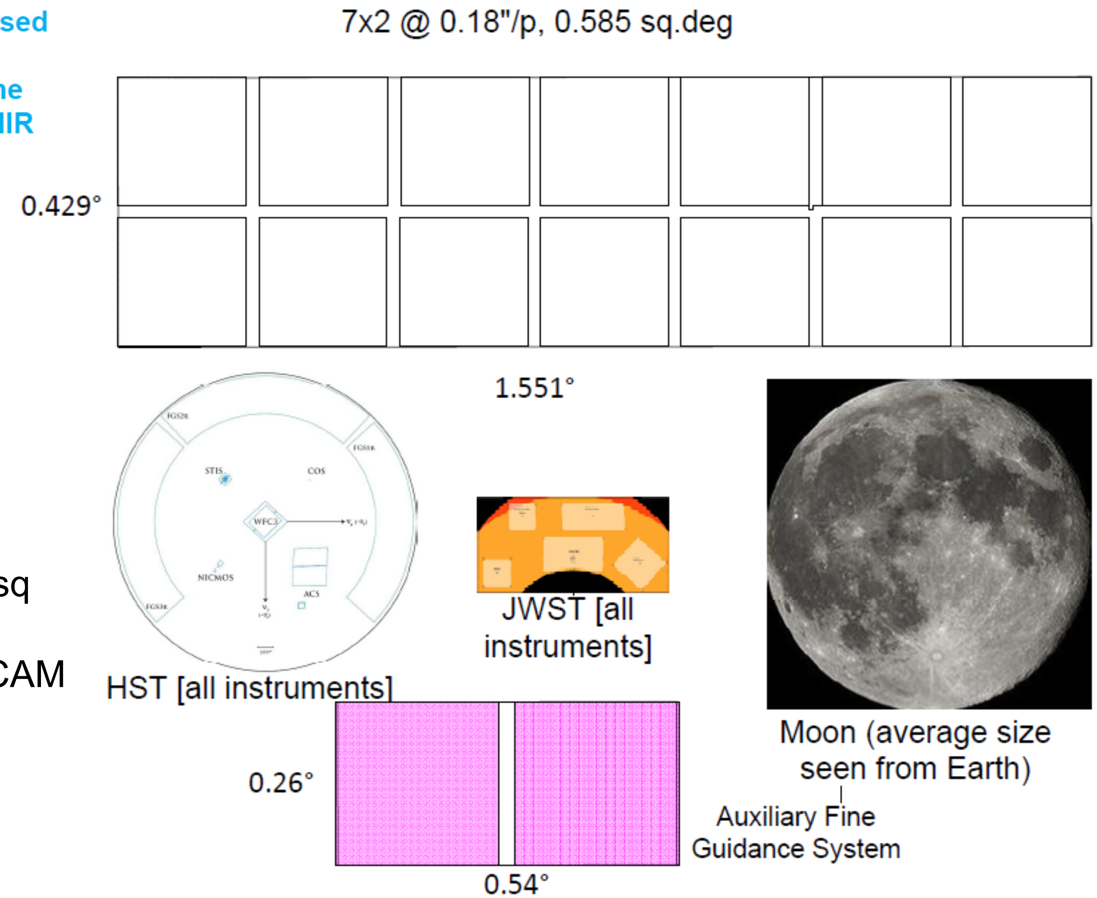
CANDELS fields on DRM1 focal plane



DRM2 Field of view & focal plane layout

Channel field layout for WFIRST “DRM2”

The Field of view of the single channel which can be used in imaging (Im), BAO spectroscopy (Sp), or SN spectroscopy (SNSp) mode is shown to scale with the Moon, HST, and JWST. Each square is a 16Mpix vis-NIR sensor chip assembly (SCA), 10 um pixels

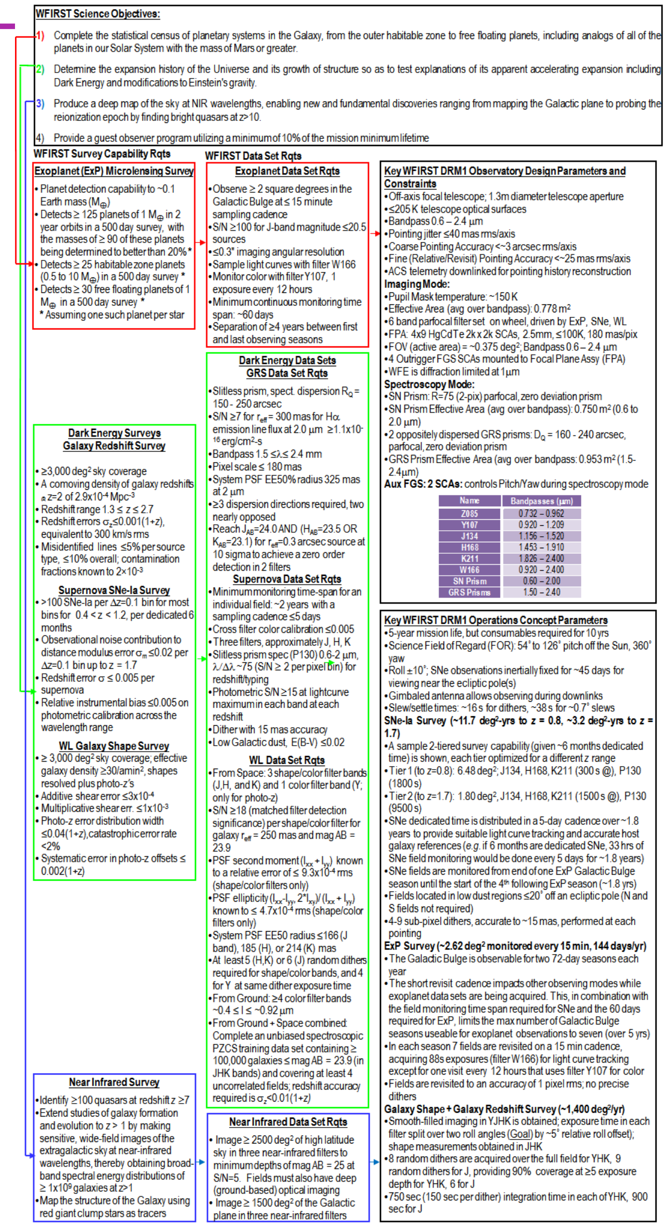


WFIRST-JWST Focal plane Comparison

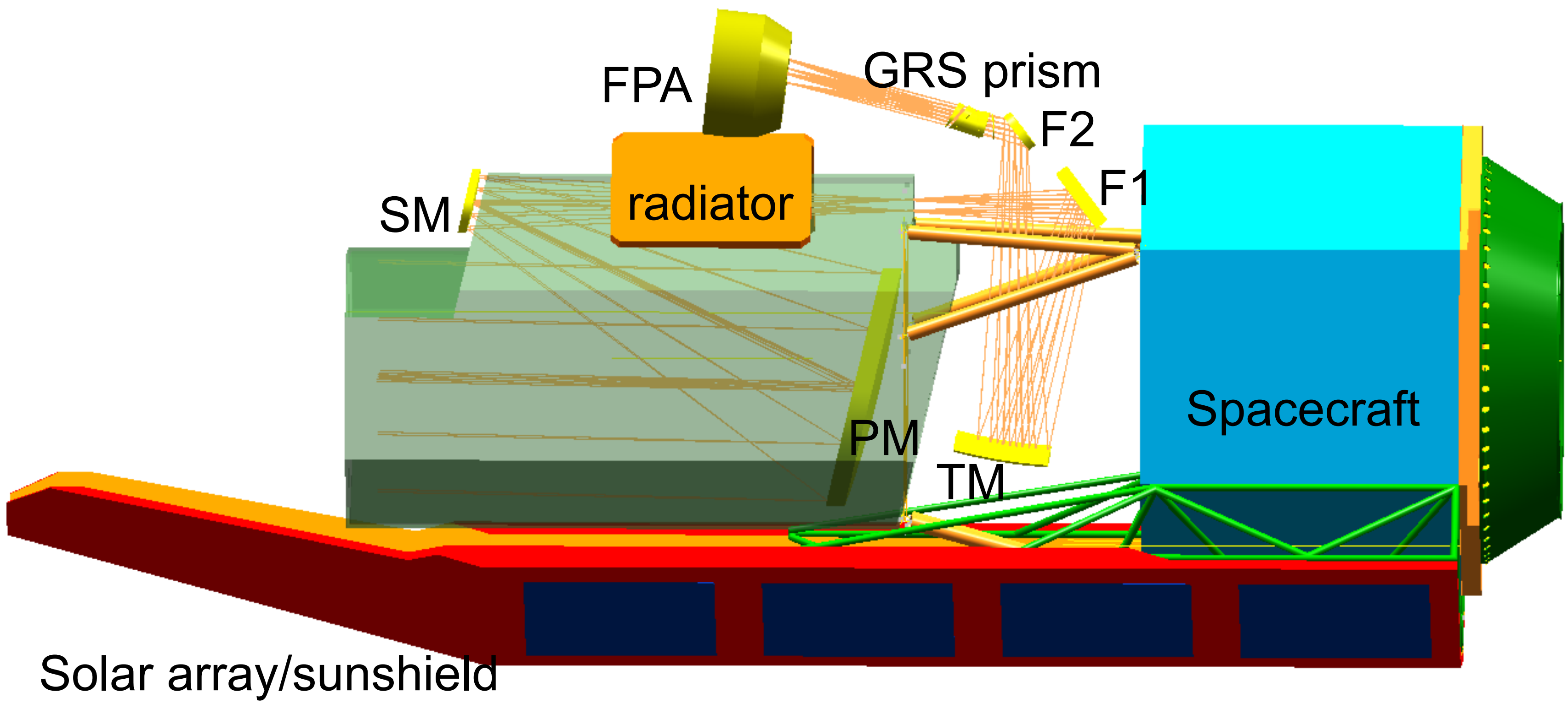
- Area is 226x larger than NIRCAM (0.585 sq vs 0.00259 degrees)
- Focal plane has 7x more pixels than NIRCAM short wave cameras (235 vs 33 Mpix)

DRM1 One Page Flow Down

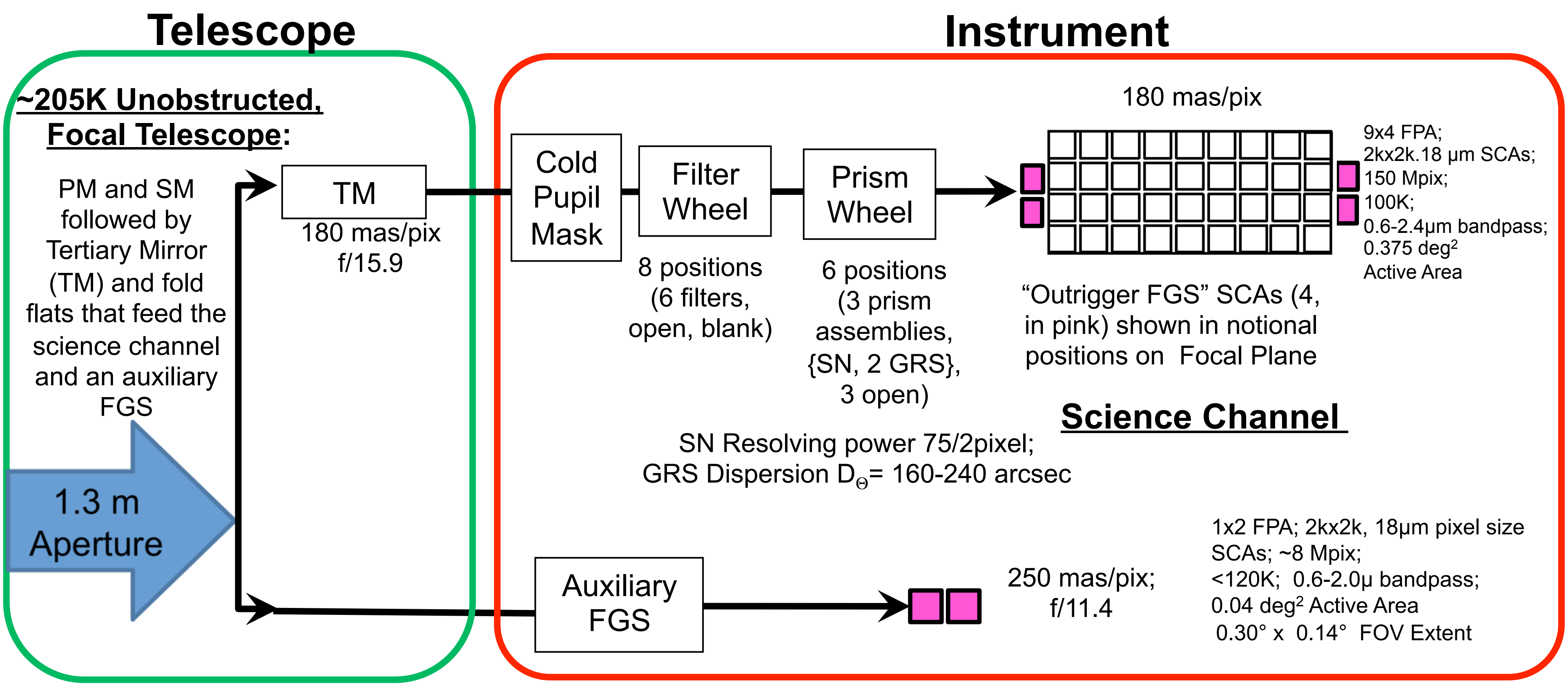
- Substantiate that the DRM1 can achieve the science objectives mandated by NWNH.
- Trace WFIRST's Science Objectives to a set of derived Survey and Data Set requirements, and flow these down to a responsive Observatory Design and Ops Concept
- DRM1 is a Reference Design
  - Multiple designs can meet the science requirements



WFIRST DRM1
Observatory Layout & Ray Trace

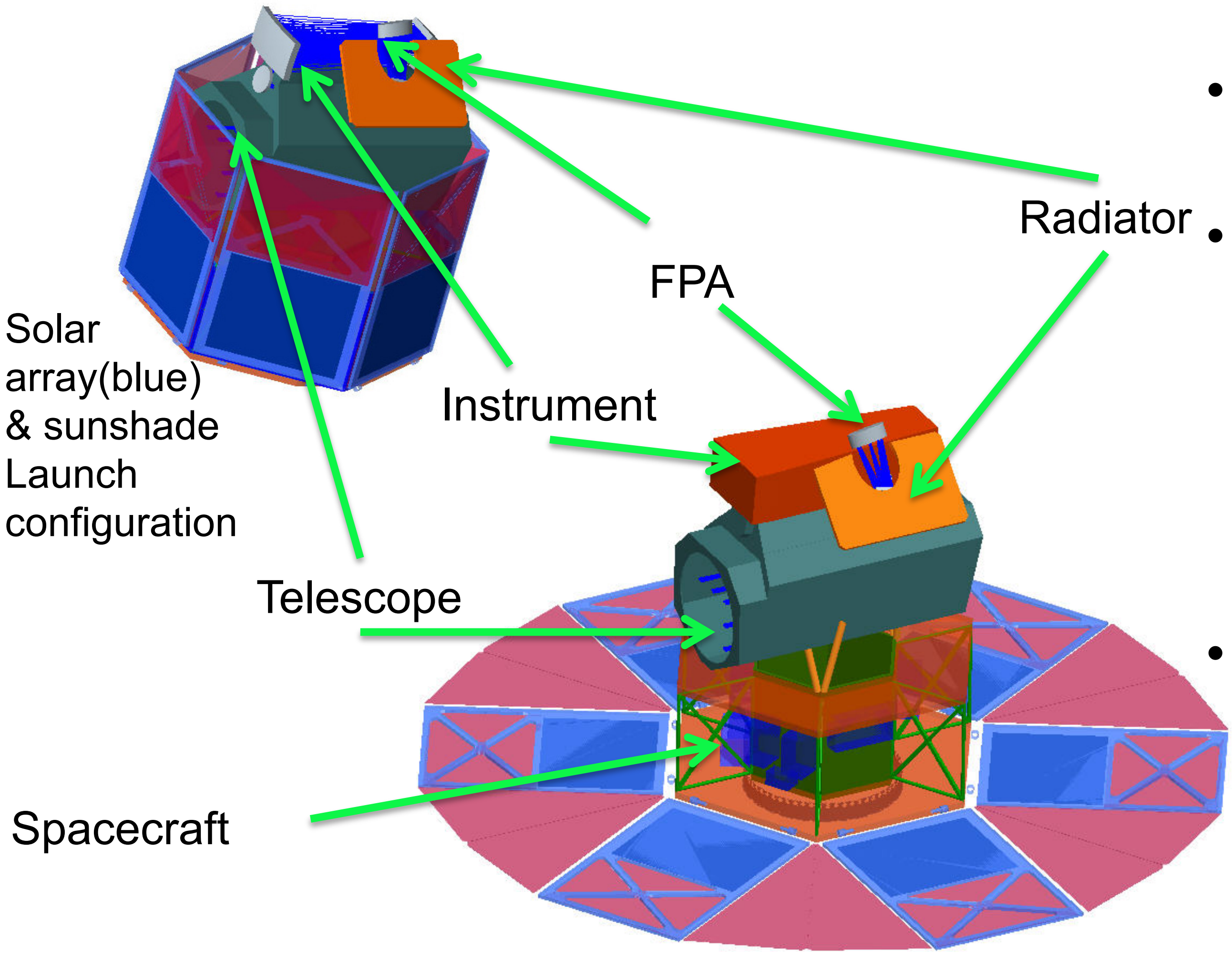


WFIRST DRM1
Payload Optics Block Diagram



GRS = Galaxy Redshift Survey
FGS = Fine Guidance Sensor: Outrigger FGS used during imaging, Auxiliary FGS used during spectroscopy
SN = Type1a Supernovae

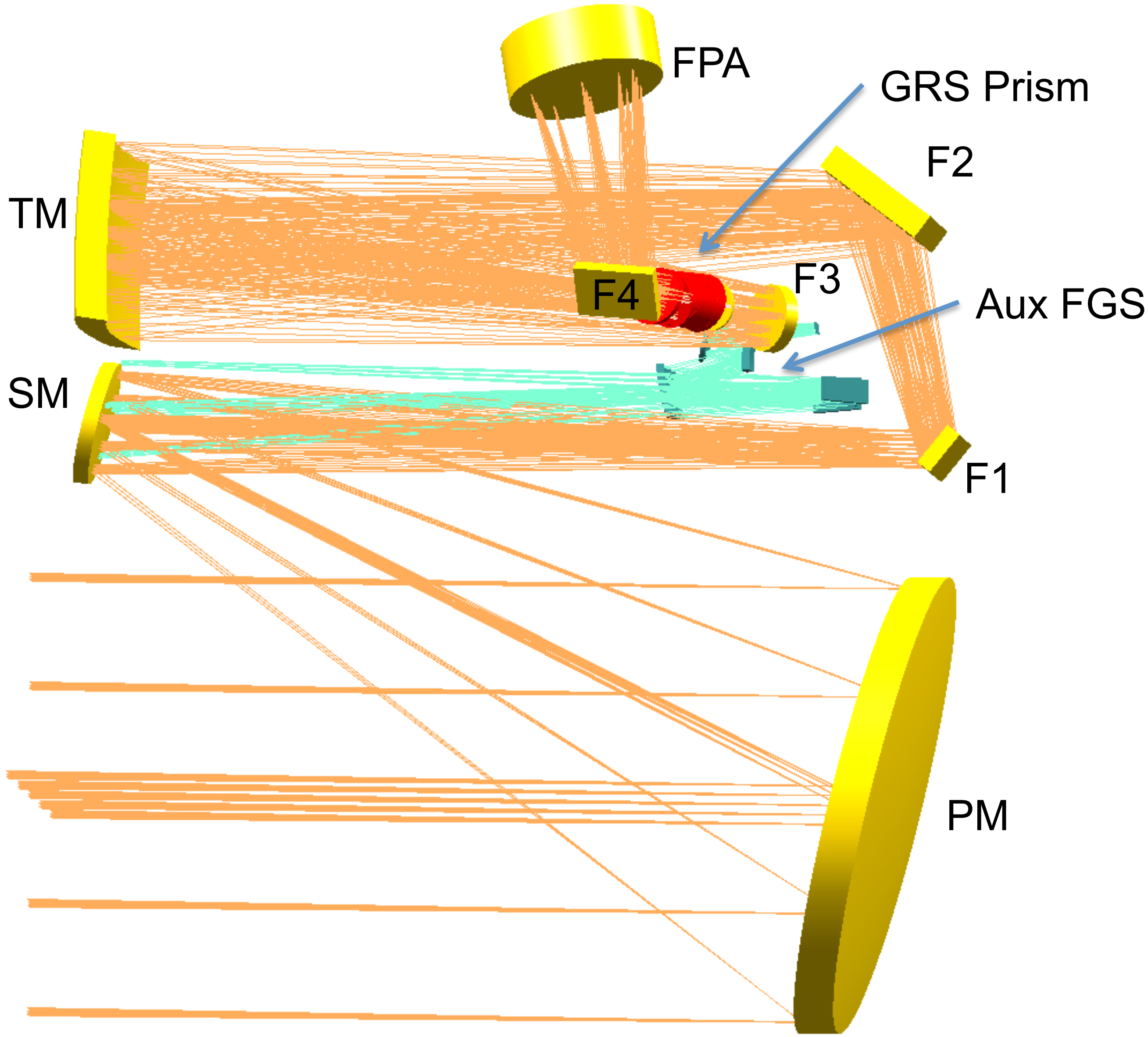
WFIRST DRM2 Observatory Layout



Solar array(blue) & sunshade, deployed

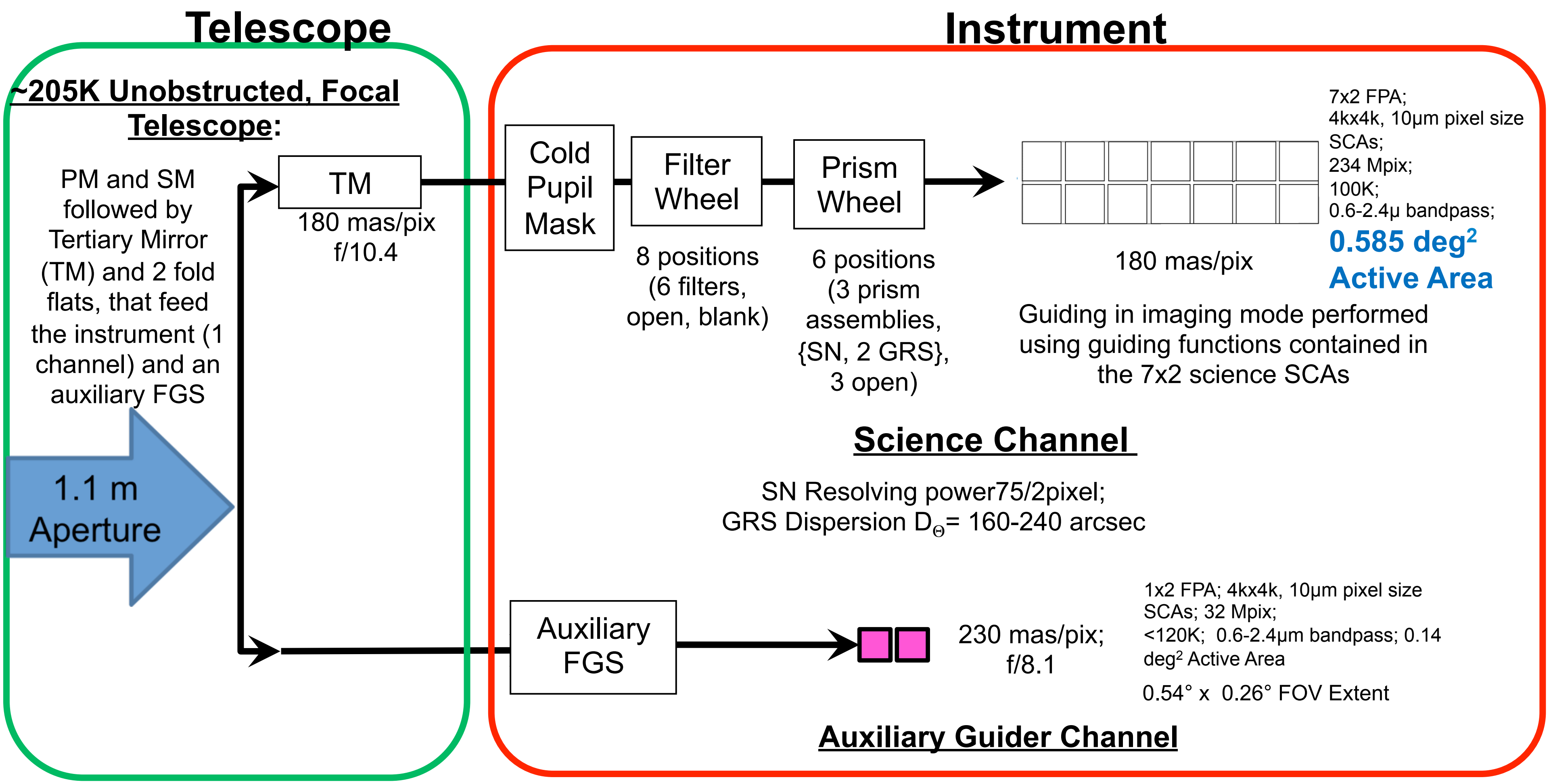
- Sun is at bottom in this view
- WMAP-like progression from warm solar array (300K) to cold focal plane (100K) from bottom to top
- Overall dry mass 500+ kg less than DRM1

DRM2 – Ray Trace



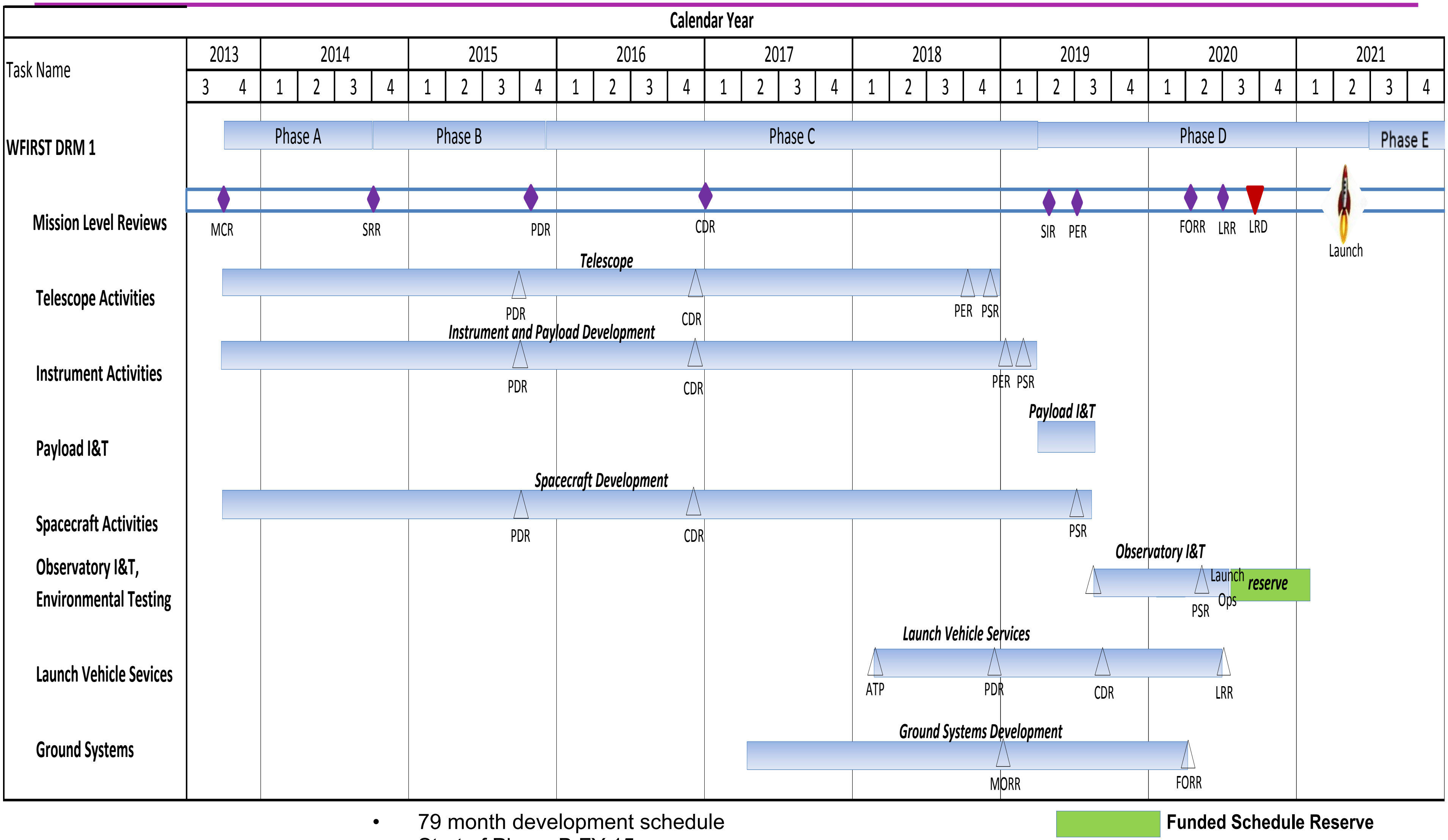
- Compact packaging has a lower cg which translates into lower mass
- Also enables deployable sunshade, horizontal optical axis
- Fits within lower cost launch vehicle even with mass margins required by CATE

WFIRST DRM2
Payload Optics Block Diagram



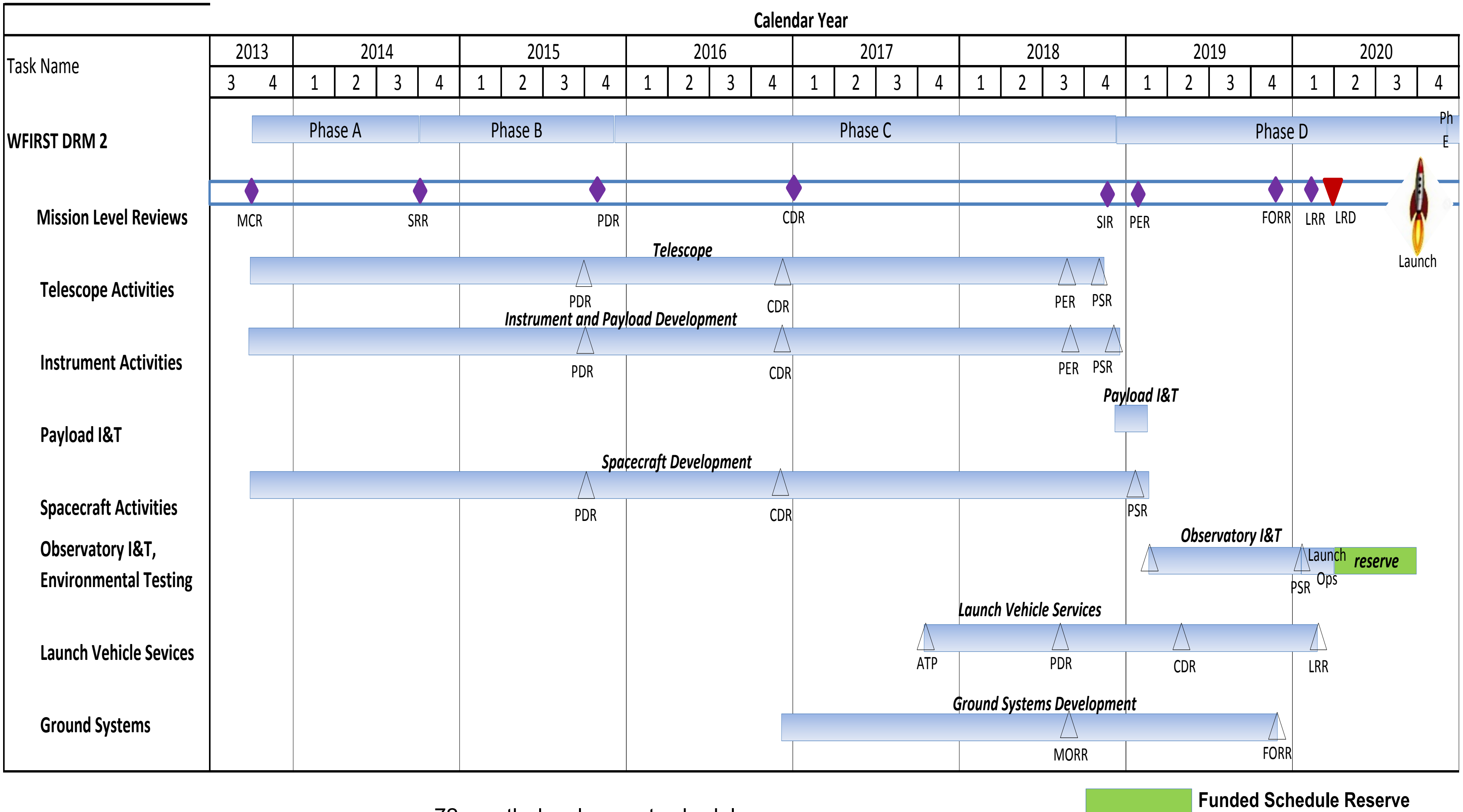
GRS = Galaxy Redshift Survey
FGS = Fine Guidance Sensor: Science SCA (guiding windows) used during imaging, Auxiliary FGS used during spectroscopy
SN = Type1a Supernovae

WFIRST DRM1 Schedule Estimate



- 79 month development schedule
- Start of Phase B FY 15
- Launch Readiness Date Sept ember 2020
- 7 month schedule reserve

WFIRST DRM2 Schedule Estimate



- 72 month development schedule
- Start of Phase B FY 15
- Launch Readiness Date April 2020
- 6 month schedule reserve

WFIRST DRM1 Cost Estimate

- The IDRM life cycle cost estimate last year was $1.63B. The ICE for the IDRM was 7% higher than the Project's estimate.
- The DRM1 configuration under study incorporates only one significant change vs. mid-2011 IDRM configuration.
  - Payload optical channels are reduced from 3 to 1.
- Assessment of the resulting cost savings from these changes indicates that the overall cost savings are modest - less than $125M.

DRM1 (FY15 Start) - 1.3m, single channel		FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	TOTAL
DRM1 (FY15 Start) (Schedule & Cost)		Det. Dev	Phase A	Phase B	Phase C				Phase D		Phase E					Phases A-E
		MCR	SRR/ MDR	PDR	CDR			NIR Delivery SIR		Launch					EoM-P	
Budget Req'ts	Total RYM$'s	$13	$26	$139	$113	$116	$423	$362	$218	$147	$55	$57	$58	$60	$41	$1,816
	Total FY12M$'s	$13	$25	$129	$102	$102	$362	$302	$177	$116	$43	$43	$43	$43	$29	$1,515

- As a result of this, HQ has deferred performing the CATE on DRM1, given that the savings are modest and the CATE last year was in good agreement (7%) with the WFIRST Project's estimate.
- NOTE: based on the optimizations that have been studied on DRM2, should the desired path forward be a "DRM1-like" configuration, *off-axis telescope with an aperture larger than 1.1 m*, then our recommendation is that follow-on efforts examine the potential for extending the optimizations developed in the DRM2 configuration (more to follow).

WFIRST DRM2 Cost Estimate

- The DRM2 mission concept combines the cost efficiencies of the 2010 Probe mission concept with the payload simplicity and capability of the single channel DRM1.
- Significant mass reductions were enabled by rethinking major elements such as the solar array-sunshield, payload orientation, and spacecraft mechanical load path.
- Results in robust mass margins within capability of F-9 launch vehicle.
- The Project’s estimate of the development cost of DRM2 (cost to clear the tower) is $870M ($FY12).
  - The comparable ICE development cost for the Probe in 2010 was approximately $960M ($FY12). The historical Probe ICE estimate has been adjusted to use the identical F-9 launch vehicle cost used in the DRM2 estimate to allow a comparison.

DRM2 (FY15 Start) - 1.1m, single channel		FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	TOTAL
DRM2 (FY15 Start) (Schedule & Cost)		Det. Dev	Phase A	Phase B	Phase C			Phase D		Phase E				Phases A-E
		MCR	SRR/ MDR	PDR	CDR		SIR	NIR Delivery	Launch			EoM-P		
Budget Req'ts	Total RYM$'s	$13	$26	$81	$148	$153	$198	$199	$143	$61	$48	$46	$8	$1,112
	Total FY12M$'s	$13	$25	$75	$134	$134	$170	$166	$116	$48	$37	$35	$6	$945

- The changes incorporated into the DRM2 configuration show promise for follow-on study.
- With more detailed engineering effort, the potential exists for exploiting some of the available margin to increase the telescope aperture and size of the focal plane, but staying within the low cost framework.
- Additional effort could also be applied to examine the cost benefit trade-off of additional redundancy in the spacecraft and instrument to enable potential extended operations of this low-cost WFIRST mission.
- DRM2 configuration **requires investment** in the H4RG detectors

Conclusion

- The SDT and Project have completed the action of developing two compelling mission concepts.
- DRM1: Fully responsive to the objectives of NWNH at reduced cost
- DRM2: Extraordinary low-cost near-infrared survey opportunity. The limited 3 year life precludes full compliance with NWNH goals.
- Recommended path forward:
  - The optimizations developed for DRM2 indicate that there is a scientifically compelling, medium-cost trade space, for developing a near infrared survey mission.
  - Refine the innovations developed in DRM2 into a “DRM1-like” mission concept; determine whether performance of this new concept can be fully responsive to NWNH.

- ***DRM1 and DRM2 are both compelling opportunities for wide-field near-infrared surveys of critical importance to a broad spectrum of astronomical disciplines.***
- ***Incorporating the optimizations that enabled DRM2 into DRM1 has the potential of creating an extraordinary opportunity to deliver the science required of NWNH at a medium class budget.***